Hyperion-II^D: A preclinical PET/MRI insert using digital Silicon Photomultipliers

Jakob Wehner[1], Bjoern Weissler[2,3], David Schug[1], Peter Dueppenbecker[4], Pierre Gebhardt[4], Benjamin Goldschmidt[1], Andre Salomon[5], Rene Botnar[4], Fabian Kiessling[1], and Volkmar Schulz[1,3]

[1]*Institute for Experimental Molecular Imaging, RWTH Aachen University, Aachen, NRW, Germany,* [2]*Institute of High Frequency Technology, RWTH Aachen University, NRW, Germany,* [3]*Philips Research Europe, Aachen, NRW, Germany,* [4]*King's College London, London, United Kingdom,* [5]*Philips Research Europe, Eindhoven, Netherlands*

TARGET AUDIENCE: This abstract is addressed to an audience interested in the development of integrated hybrid imaging devices (PET/MRI).

INTRODUCTION: The combination of Magnetic Resonance Imaging (MRI) and Positron Emission Tomography (PET), which allows the visualization of metabolic processes on cellular level, endeavored several research groups to develop hybrid PET/MRI systems. In difference to solutions presented by other groups so far, we have developed a fully digital, preclinical PET insert which employs a digital version of Silicon Photomultipliers (dSiPM) and operates most of the PET electronics inside the MRI system's bore. In this work, we assess the PET performance as well as the MR-compatibility of our system in combination with a 3T clinical MRI scanner. In addition to these technical studies, we performed first in-vivo experiments which demonstrates the imaging capabilities.

MATERIALS and METHODS: The Hyperion-II^D PET insert (Figure 1) is designed to be operated inside a clinical MRI system (Philips Achieva). Details about the architecture can be found in [1,2].

PET performance: We studied PET performance parameters such as the energy resolution (ER), coincidence timing resolution (CRT), spatial resolution and sensitivity for different operating parameters (activity, trigger settings, operation temperature).

MR-compatibility assessment: On the MRI side, we performed B_0 distortion map scans (FFE sequence, TR/TE: 400/2.6ms, TE extension: 1ms, Voxel size: 2×2×2mm³) as well as B_1 map scans (SE based dual angle technique, saturation delay: 250ms, VS: 0.5x0.5x0.5mm³) to evaluate the influence of the PET insert on the B_0 and B_1 field homogeneity. Dedicated noise scans as well as SNR measurements were conducted to evaluate the MRI system's SNR performance under simultaneous imaging conditions. The influence on the gradient performance was studied by measuring the phase advance originating from induced eddy currents in the PET detector's hardware. On the PET side, we investigated the influence on the PET performance by monitoring the energy and timing resolution as well as environmental parameters under different MRI conditions (inside/outside the B_0 field, application of intense RF dominated sequences, gradient stress tests using dedicated sequences). In addition, normal MR imaging protocols (SE, FFE, EPI and TSE sequences) are applied to relate these results to more realistic imaging scenarios.

In-vivo experiments: We used a slowly growing human breast tumor model (MDA-231) to demonstrate the feasibility of in-vivo studies with our MRI-PET insert. The tumor cells were injected subcutaneously in the femur of a female mouse (age: 55days, weight: 19g, breed: Balb/c nu/nu) and a longitudinal study was performed 4, 16 and 37 days after injection. All animal procedures were approved by the Maastricht University ethical review committee and were performed according to the Dutch national law and the institutional animal care committee guidelines.

RESULTS and DISCUSSION: *PET performance:* The PET system performed stably for a wide range of parameters: we measure an ER of about 12.4%, an isocenter sensitivity of > 3% (for most trigger configurations) and a CRT between 260/440/540/1200ps for trigger scheme 1/2/3/4. The spatial resolution is in the range of about 0.8mm.

MR-compatibility assessment: On the MRI side, we observe a clear influence on B_0 field homogeneity (without PET: volume RMS (VRMS) = 0.03ppm, Peak-To-Peak value (PTPV) = 0.28ppm; with PET: VRMS = 0.28ppm, PTPV = 1.2ppm). Due to the large amount of material with positive susceptibility brought inside the MRI system's FOV, the presence of the PET causes a 2nd order distortion profile in axial direction. After compensating this 2nd order distortion using an automatic high-order shim, we measure a VRMS value of 0.08ppm and a PTPV of about 0.71ppm. A comparison of acquired B_1 maps without and with PET insert shows only minor influences of about +/-5% in the marginal regions of the RF coil's sensitive volume. Regarding the SNR performance, we measure an acceptable level of noise floor degradation (2-15% degradation, no functional dependence to the amount of radioactivity) after almost eliminating the main noise source which was the switched mode power supply unit (PSU). Regarding the gradient performance, the measured phase shifts maps show a clear creation of eddy currents when the Z gradient is applied and the PET insert is installed. This phase shift leads to ghosting artifacts when EPI sequences with a Z gradient as read-out gradient are used. On the PET side, we almost exclusively observe an influence on the PET performance, namely a degradation of the ER degradation (ERD) and CRT degradation (CRTD), when highly demanding gradient stress tests are applied. In the worst case scenarios (gradient strength: 30mT/m, slew rate: 200T/m/s, switching duty cycle (SDC, time percentage in which the gradient is in switching state): 80-100%), we measure an ERD of about 10% and a CRTD of 14%. In parameter ranges of imaging sequences (SDC < 20%), we hardly measure a performance degradation, meaning that for normal imaging operation, the PET performance can be regarded as unaffected.

In-vivo experiments: Figure 2 shows simultaneous acquired example images of the performed animal experiments: a T_2W TSE image is shown on the left, the acquired PET image in the middle and an overlay of both images is shown on the right. The experiment demonstrates the image quality achievable and the usability of this hybrid PET/MRI system.

CONCLUSION: We have successfully build the world's first PET insert using digital SiPMs which allows simultaneous operation inside a clinical 3T MRI system. The PET performance is stable for a large variety of operating parameters. The assessment study of the MR-compatibility shows an acceptable level of MRI performance degradation as well as no relevant PET performance deterioration. The completion of longitudinal animal studies demonstrates the stability of the PET system and the low level of mutual interference between both imaging devices.

References

[1]Weissler et al., NSS/MIC 2012, pp. 2113, DOI:10.1109/NSSMIC.2012.6551484. [2]Weissler et al., NSS/MIC 2012, pp. 2759, DOI:10.1109/NSSMIC.2012.6551628

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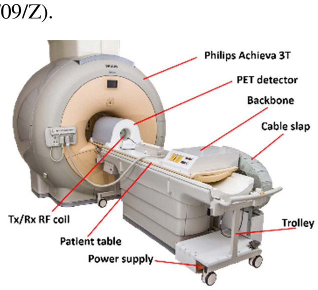

Figure 1: The Hyperion-IID PET insert installed at a clinical 3T MRI system (Philips Achieva 3T).

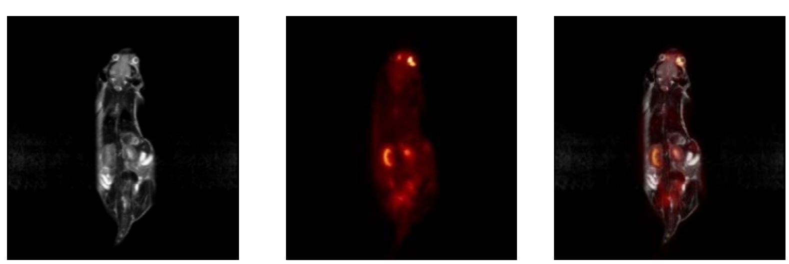

Figure 2: Example images from the longitudinal simultaneous PET/MRI study. A T_2W TSE (TE/TR:100/2400ms, Flip Angle: 90°, TSE factor: 19, Pixel size: 0.2x0.2x2mm³, Pixel bandwidth: 329Hz) image is shown on the left, a PET image in the middle and an overlay on the right.